The Galileo Spacecraft:

A Telecommunications Legacy for Future Space Flight

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Abstract

The Galileo mission to Jupiter has implemented a wide range of telecommunication improvements in response to the loss of it's high gain antenna. Among the communications enhancements that have been made are the use of advanced compression techniques, packetized telemetry, new error correcting codes and algorithms, more efficient modulation, variable transmission data rates, routine ground antenna arraying (even between continent s,) extremely sensitive ground receivers, and non-real-time automated data reconstruction. These together have resulted in a 20 dB (100 fold) increase in information being returned from the spacecraft at Jupiter, allowing the mission to meet the vast majority of it's science objectives using small, hemispherical antennas and an S-Band system. In fact, Galileo is currentl y the most advanced deep space craft in the world in terms of communications technology. While necessity dictated the use of these new techniques for Galileo, now that they have been proven in flight, they are available for use on future deep space missions. This telecommunications legacy of Galileo will aid in our ability to conduct a meaningful exploration of the solar system, and beyond, at a reasonable cost.

The Galileo Spacecraft: A Telecommunications Legacy for Future Deep Space Missions

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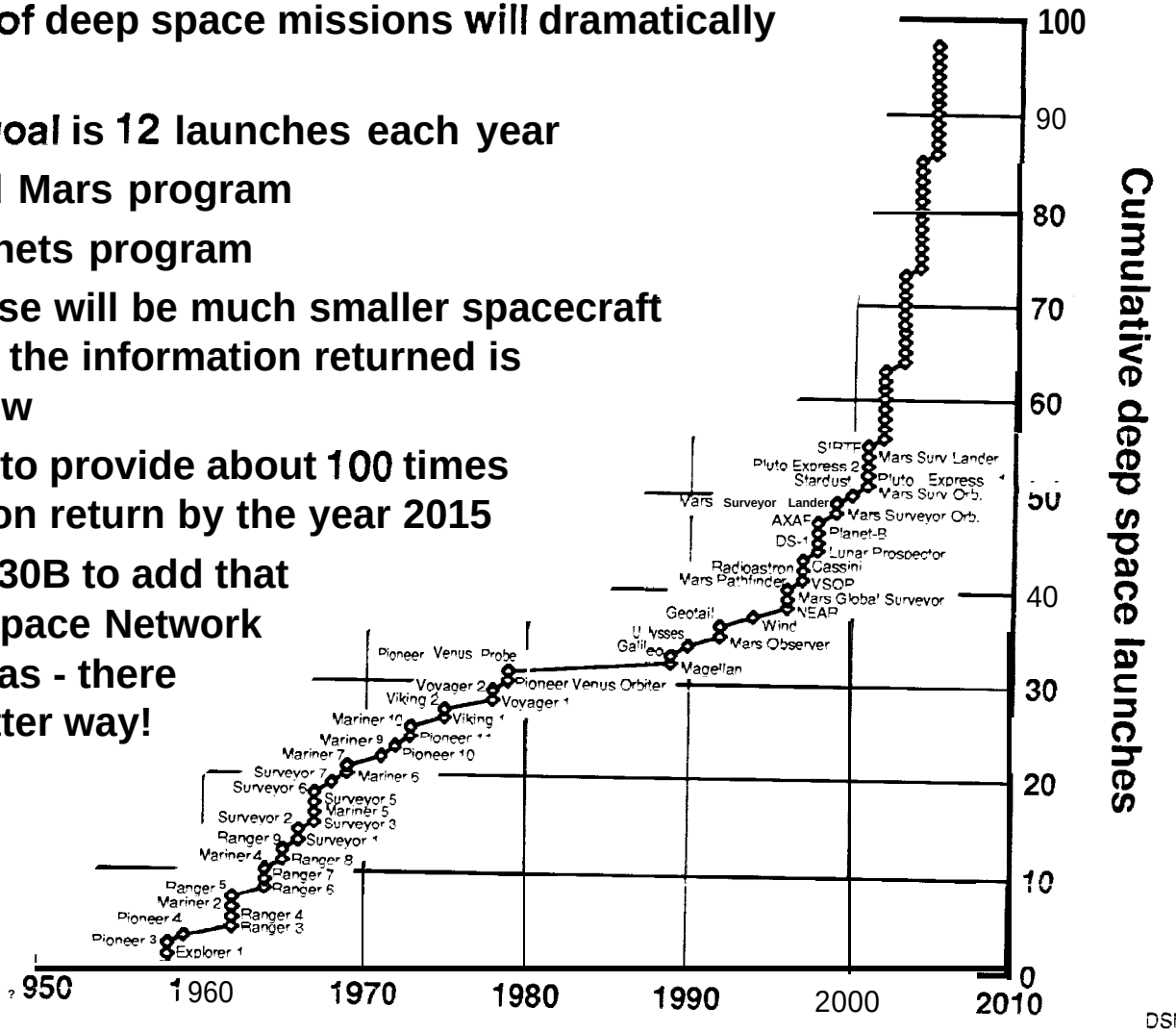
The Big Telecommunications Challenge

- **The number of deep space missions will dramatically increase**
  - **Goldin's goal is 12 launches each year**
  - **Expanded Mars program**
  - **Outer planets program**
- **Although these will be much smaller spacecraft than Cassini, the information returned is expect to grow**
- **We will need to provide about 100 times the information return by the year 2015**
- **Would cost $30B to add that many Deep Space Network (DSN) antennas - there must be a better way!**



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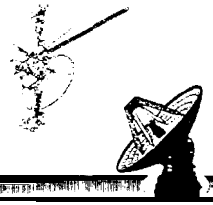
Better solution: Use the link more efficiently



- **Get back 100 times the information per unit time**
- **Connect to the DSN only 1/100 as often**
- **Build spacecraft that can survive longer periods without communications with Earth**

Galileo has done this already - because it had to!

- **Despite (in fact, because of) the loss of Galileo's high gain antenna, the spacecraft is state-of-the-art in fink efficiency**
- **Because Galileo has done this, all future deep space missions can leverage our experience to improve their own communications**
- **Because Galileo has paid for upgrades in the DSN, these capabilities are available to future missions at reduced cost**

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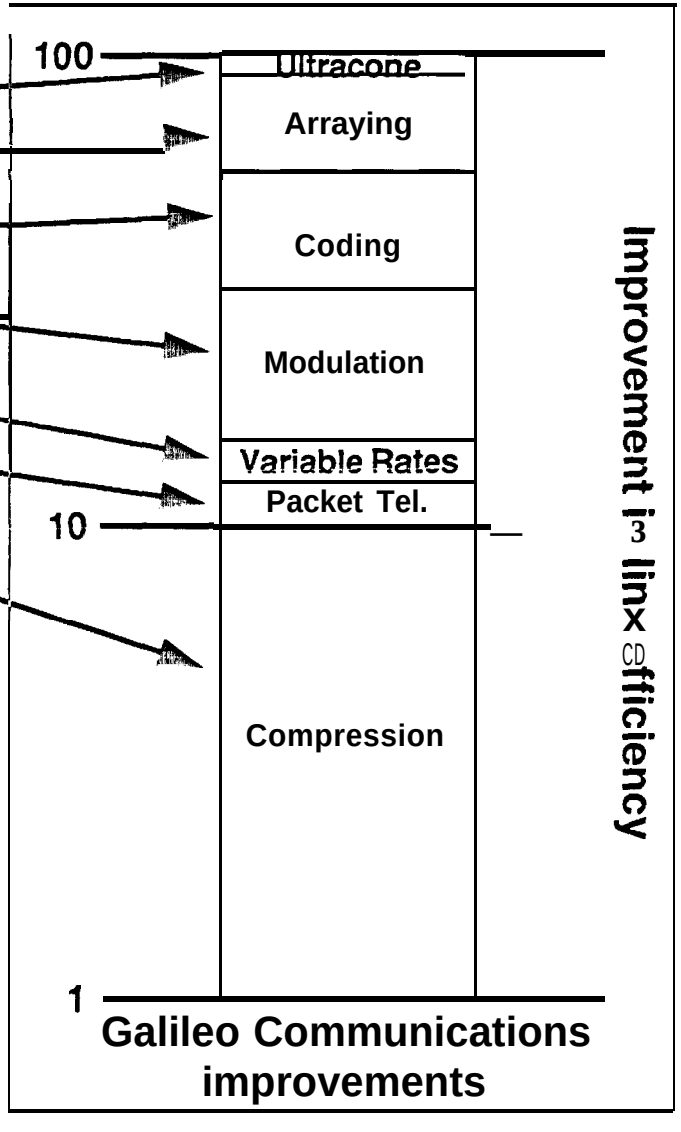
The tools Galileo has used to increase efficiency

- Optimized Signal Detector
- Antenna arraying
- Advanced error-correcting codes
- Efficient modulation
- Variable data rates
- Packet telemetry
- Data compression



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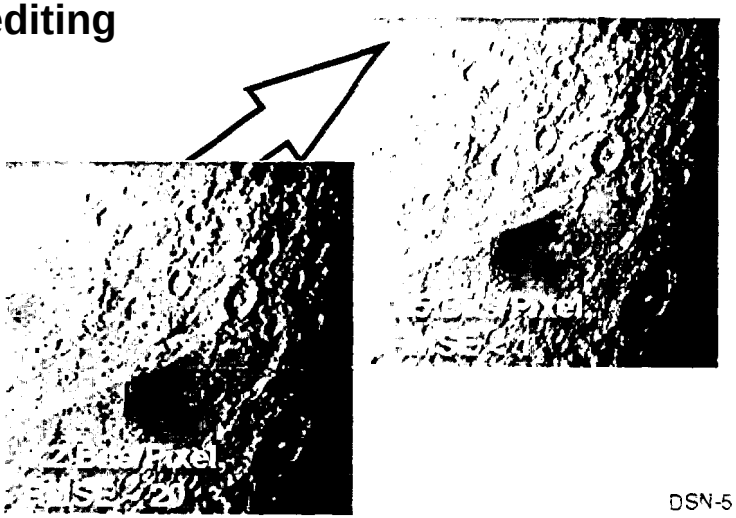
Compression

- Before GLL, deep space missions used mostly "lossless" compression
  - Low compression ratios - typically no better than 2:1
  - Well understood, deterministic errors, caused mainly by data overflow
- Galileo now uses the Integer Cosine Transform (ICT) algorithm - similar to JPEG industry standard for photographic images
  - Compression ratios can be set - typically between 5:1 and 20:1
  - New error containment strategies make this viable for deep space
  - Error artifacts are better understood do to research in support of Galileo
- Galileo was forced to determine which information is most important from each instrument and subsystem - data editing

All future deep space missions are baselining compression and editing



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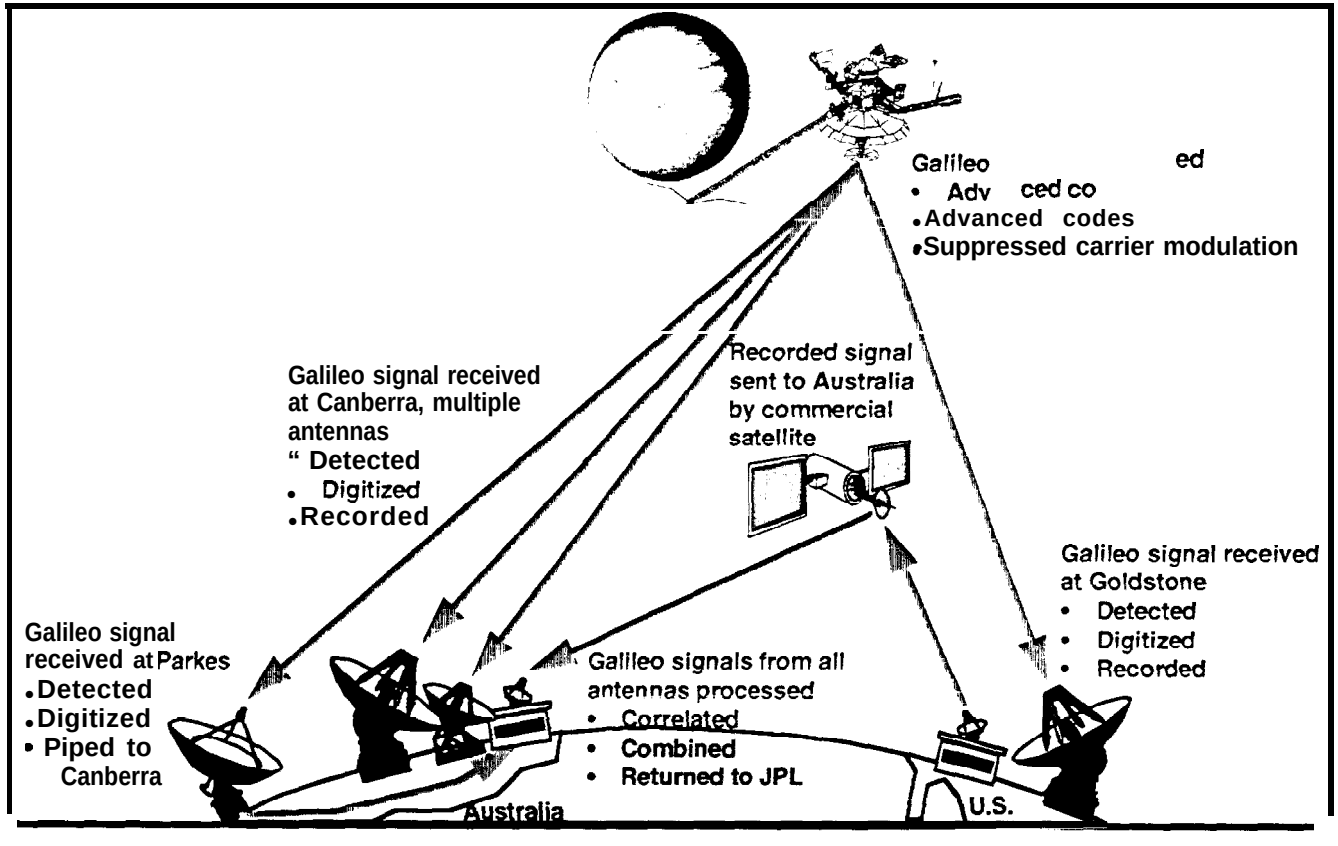
Antenna+Antenna+Antenna... Arraying

- **The DSN will not routinely encourage large arrays**
- **Arrays will be used for special mission events and to synthesize 70m antenna performance from smaller antennas - since no more 70m antennas will be built**



DSN-6
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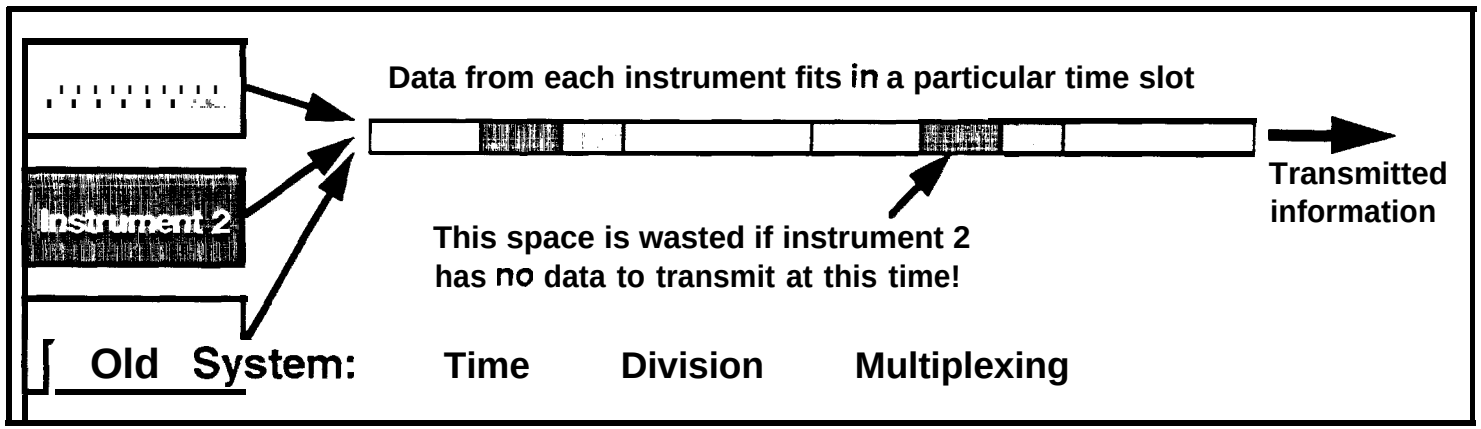
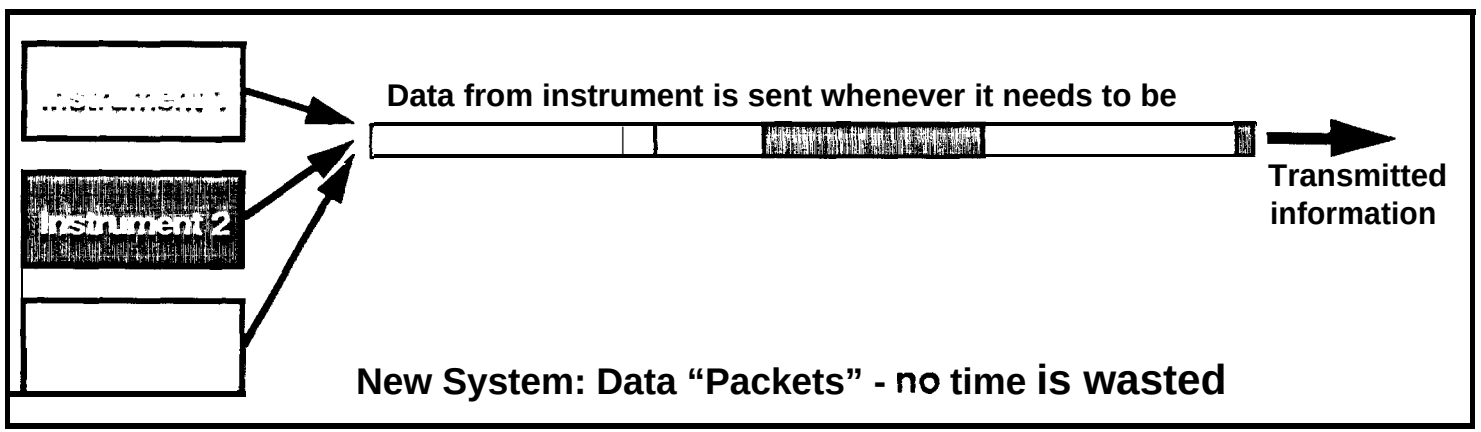
Packet Telemetry





- All future deep space missions will use packet telemetry to eliminate wasted space in the transmitted information

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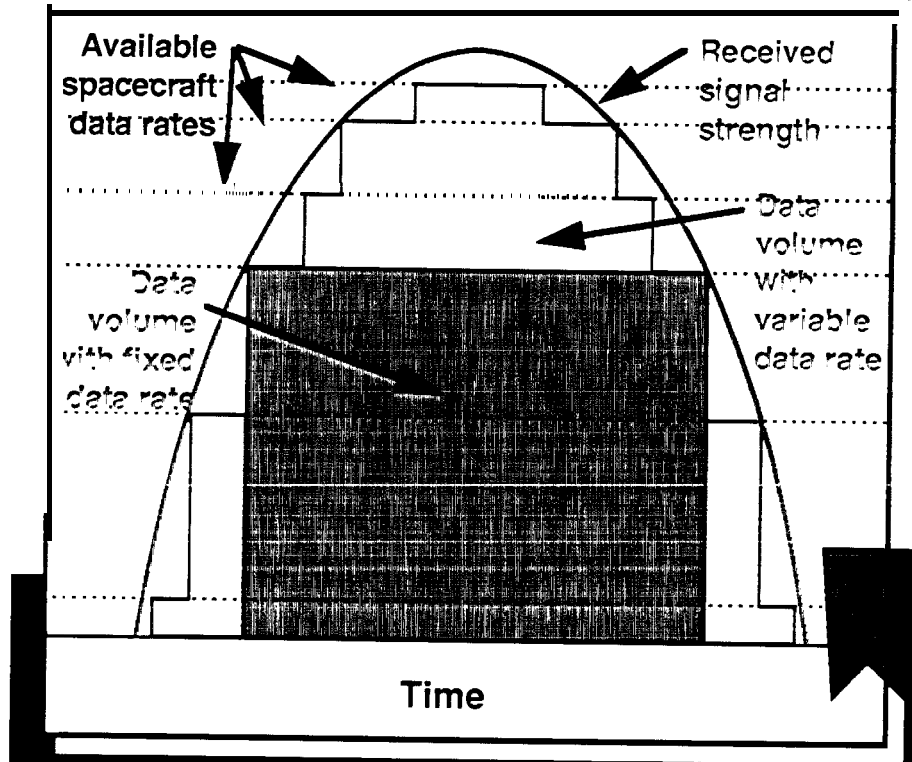
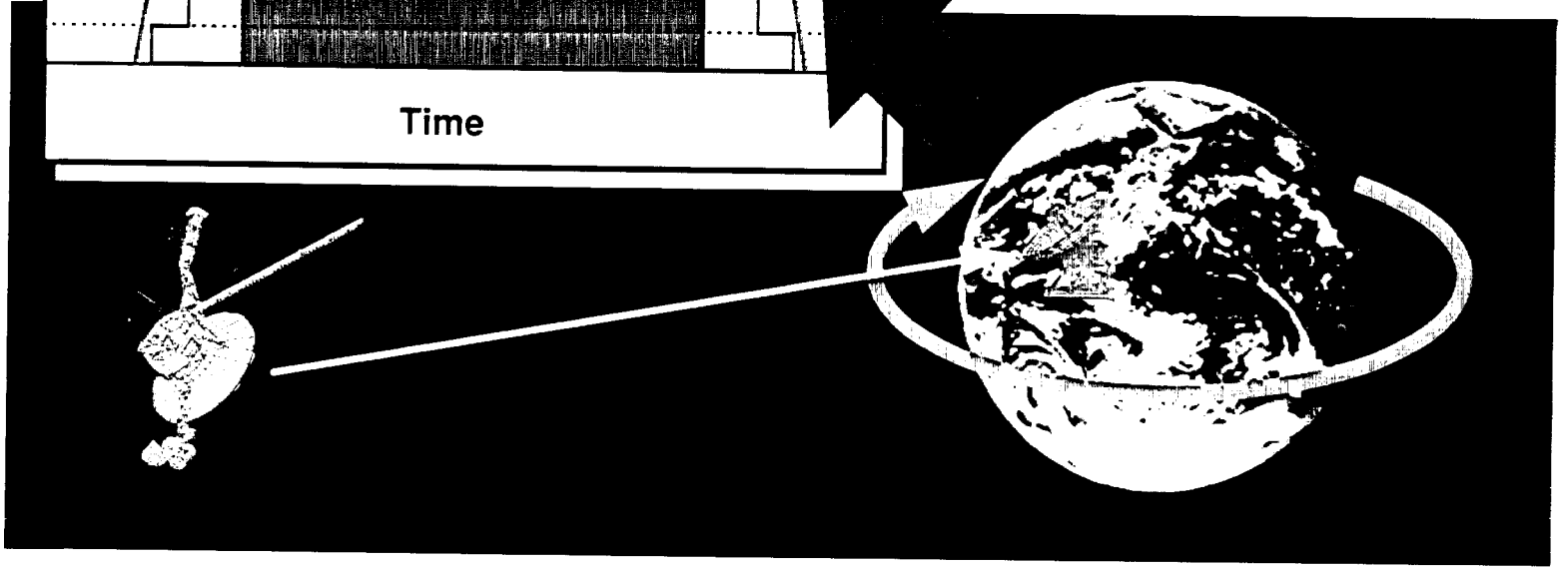
Variable data rates



- Galileo is the first deep space mission to use variable data rates during DSN passes
- Galileo must predict signal levels in advance to do this
- Future spacecraft will probably use measured uplink strength to adjust data rates
- May also use a deep space version of TCP/IP



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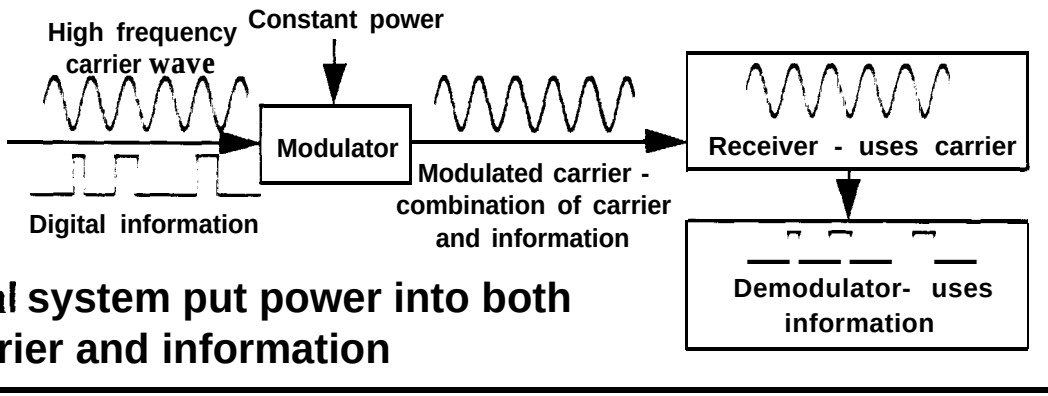
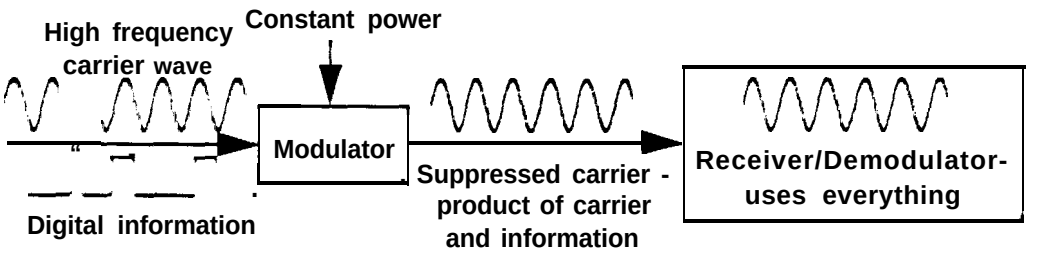
Modulation



Original system put power into both the carrier and information



The current Galileo system puts all the available power into the information stream. This is enabled by a new generation of DSN receivers (the Block V) that can demodulate this format at very low signal levels

- **Suppressed carrier modulation is now available to all future deep space missions**

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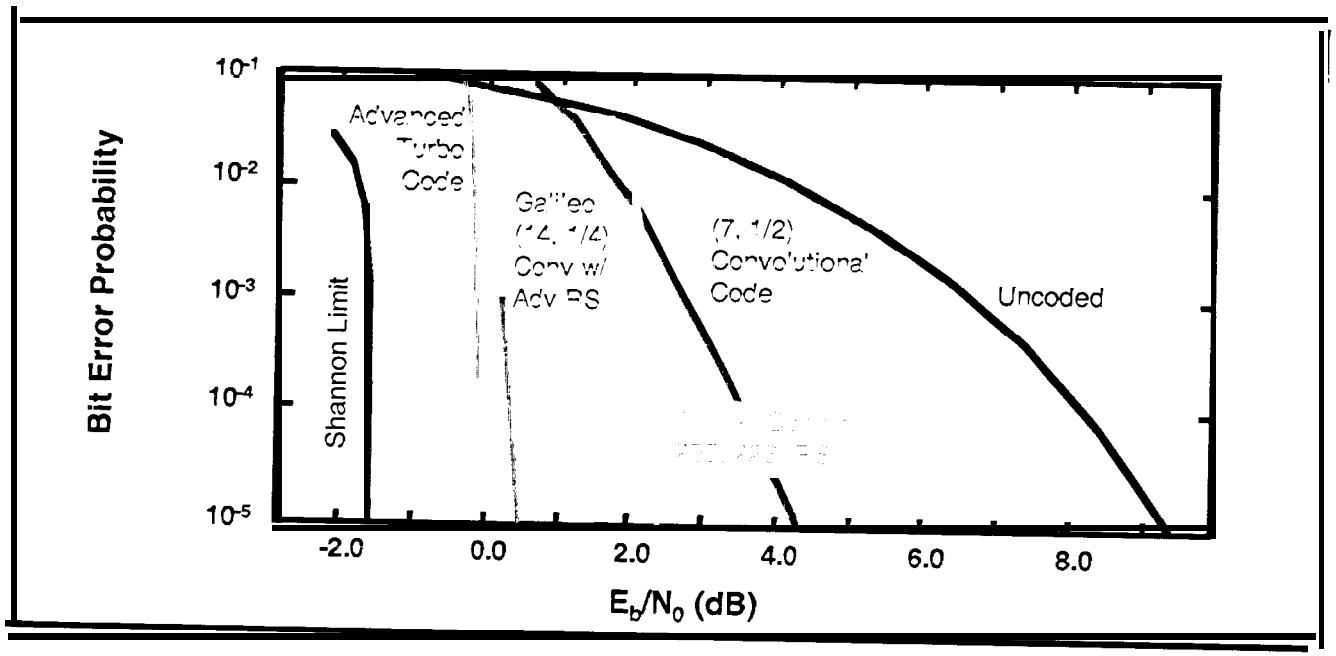
Eror-corecting codes

- Error correcting codes have been used for many years in deep space
- Galileo's codes are the best yet flown
- Among the new coding techniques on Galileo are variable redundancy, and redecoding - applicable to future codes as well
- Future missions will leverage these techniques and continue to evolve better codes



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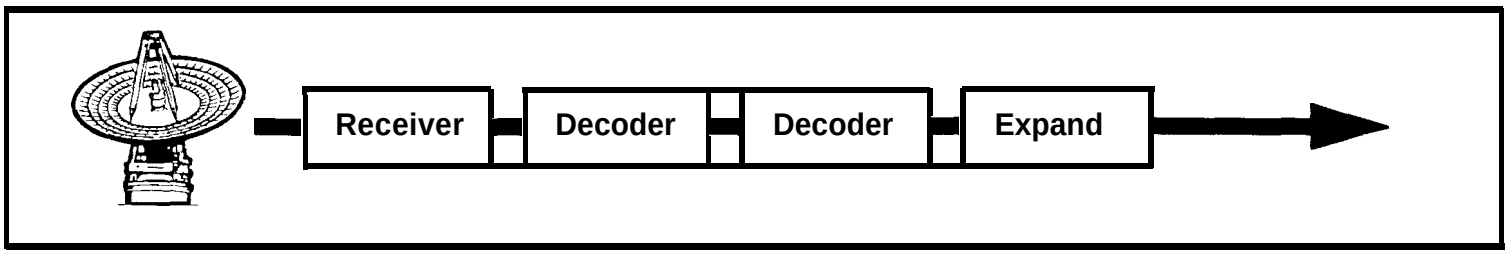
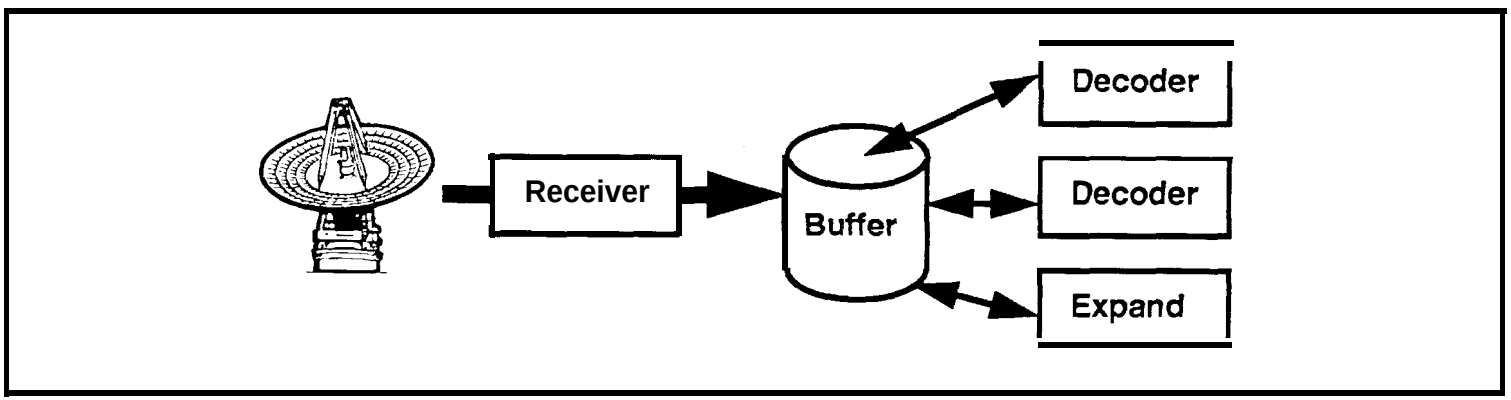
Asynchronous processing



- For Galileo, all DSN processing after bit detection is performed on demar d
- This system is more modular, efficient, and cheaper to maintain than the old serial system
- Although this does not increase link efficiency, the DSN will evolve to this architecture - a lower-cost legacy for all future missions



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Conclusion

- The Galileo spacecraft was launched as old technology
- The changes that have been made to support the S-band mission have turned Galileo into a state-of-the-art communication system
- All future planetary (and beyond) spacecraft will now be able to take full advantage of the new techniques pioneered by Galileo
- The experience with Galileo communications has led to a NASA communication roadmap for future missions